

# CYGNUS R&D Program

Lindsey Bignell, ANU Node

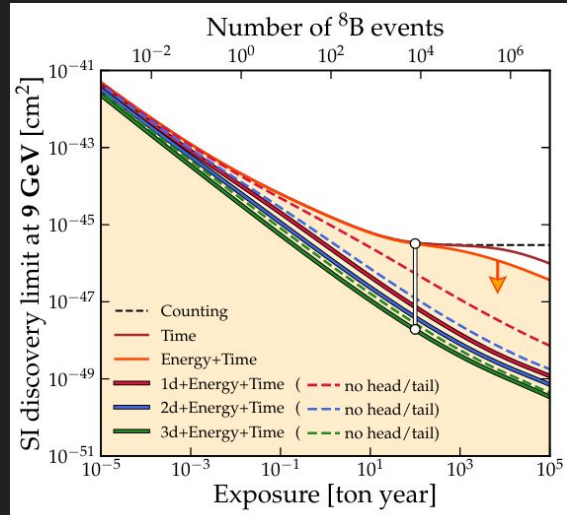
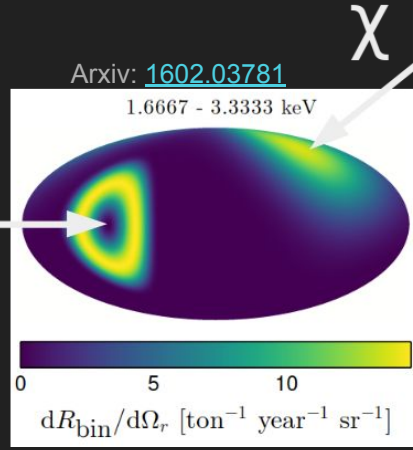
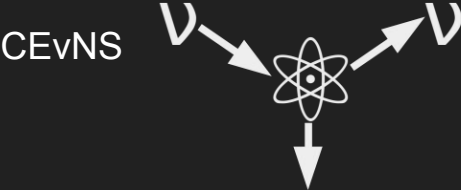
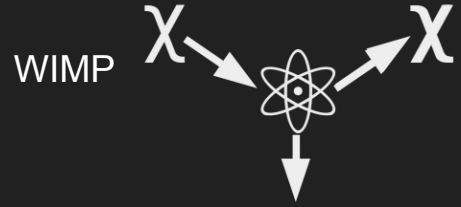


Australian  
National  
University



# Directionality: the Neutrino Fog Frontier

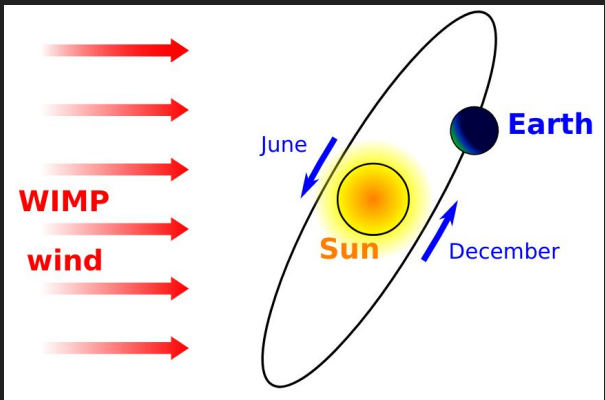
(and reject isotropic backgrounds)



Arxiv: [2102.04596](https://arxiv.org/abs/2102.04596)

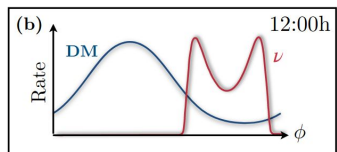
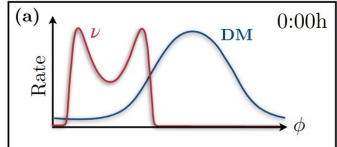
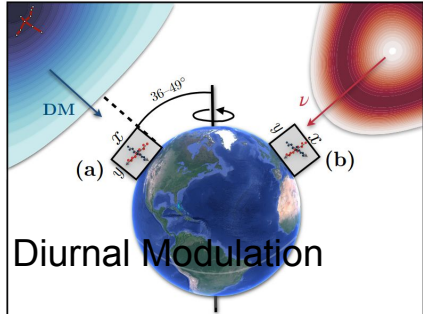
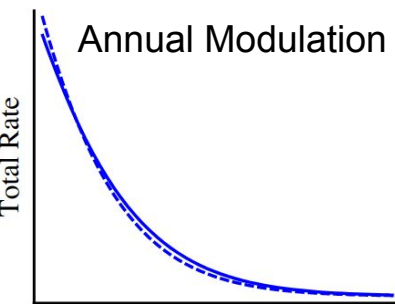
# Directionality and Astrophysics

Distinctive signature → Confirm DM

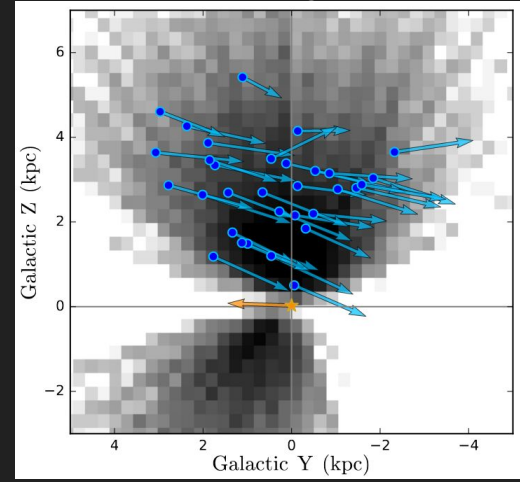


Non-directional

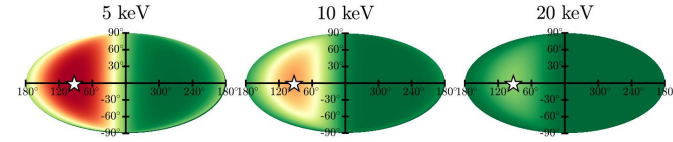
Directional



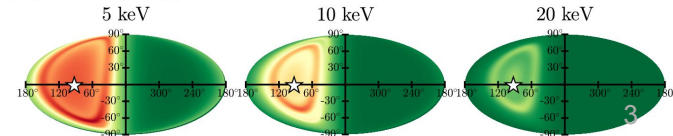
Post-discovery science



SHM



90% SHM + 10% S1



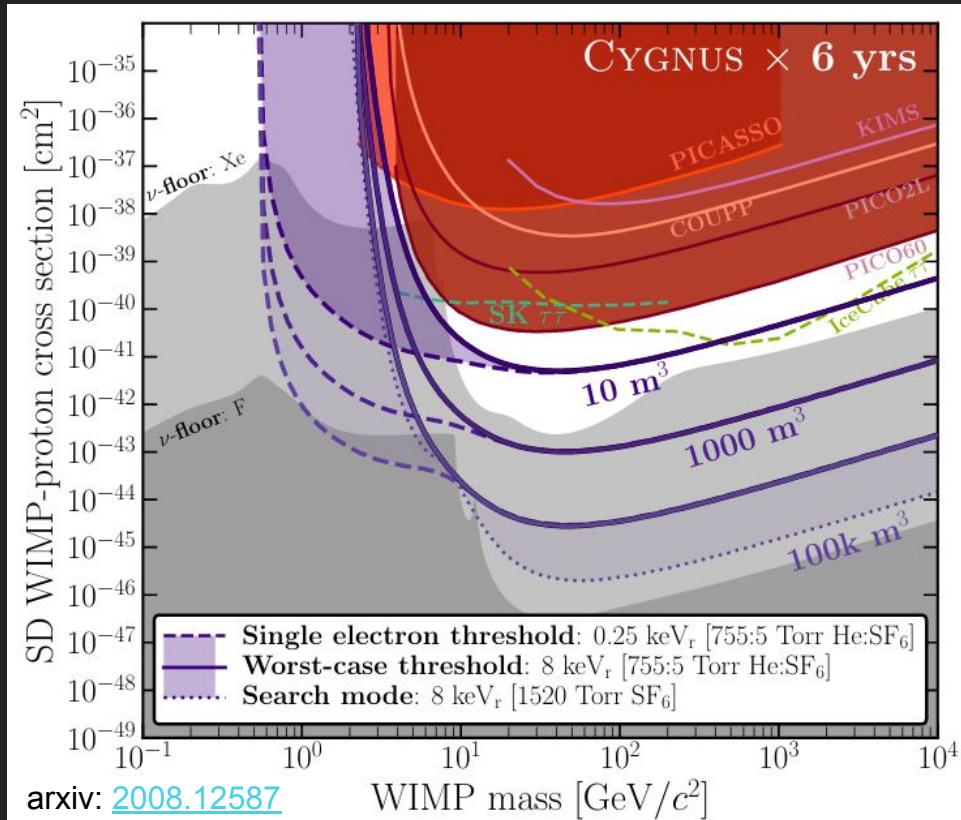
Arxiv: [1209.3339](https://arxiv.org/abs/1209.3339)  $E_{nr}$

Arxiv: [2102.04596](https://arxiv.org/abs/2102.04596)

Arxiv: [1807.09004](https://arxiv.org/abs/1807.09004)

# Spin-Dependent Sensitivity

$\text{CF}_4$  and  $\text{SF}_6$  gases  $\rightarrow$  world-leading limits with modest detectors

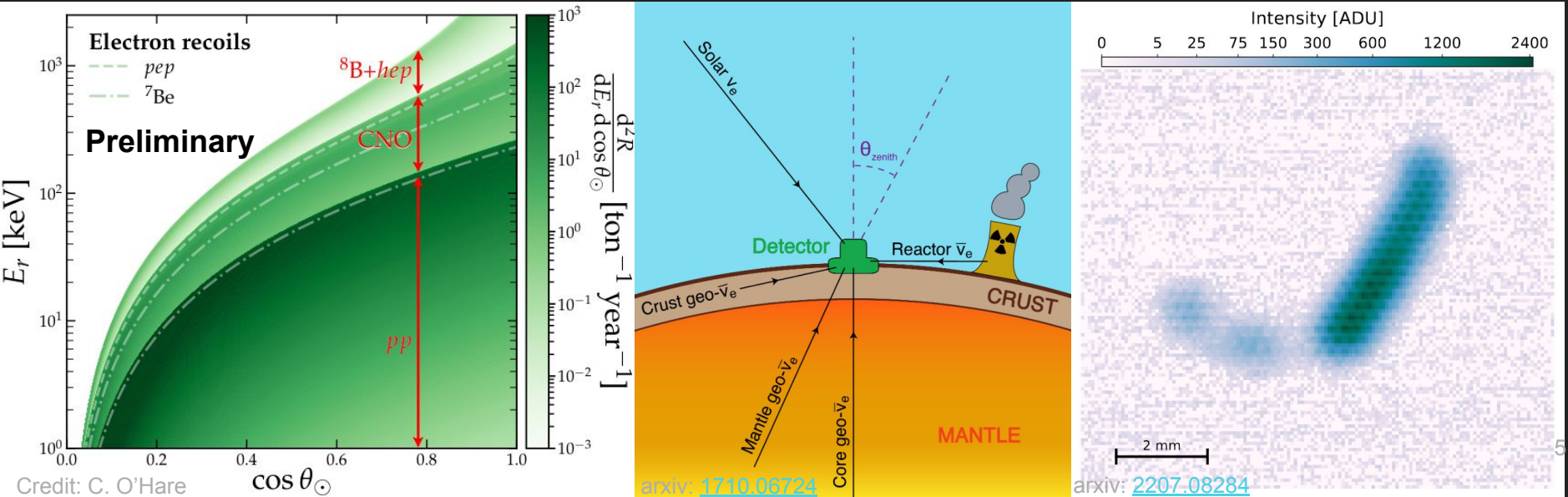


# Directionality: Non-DM Physics

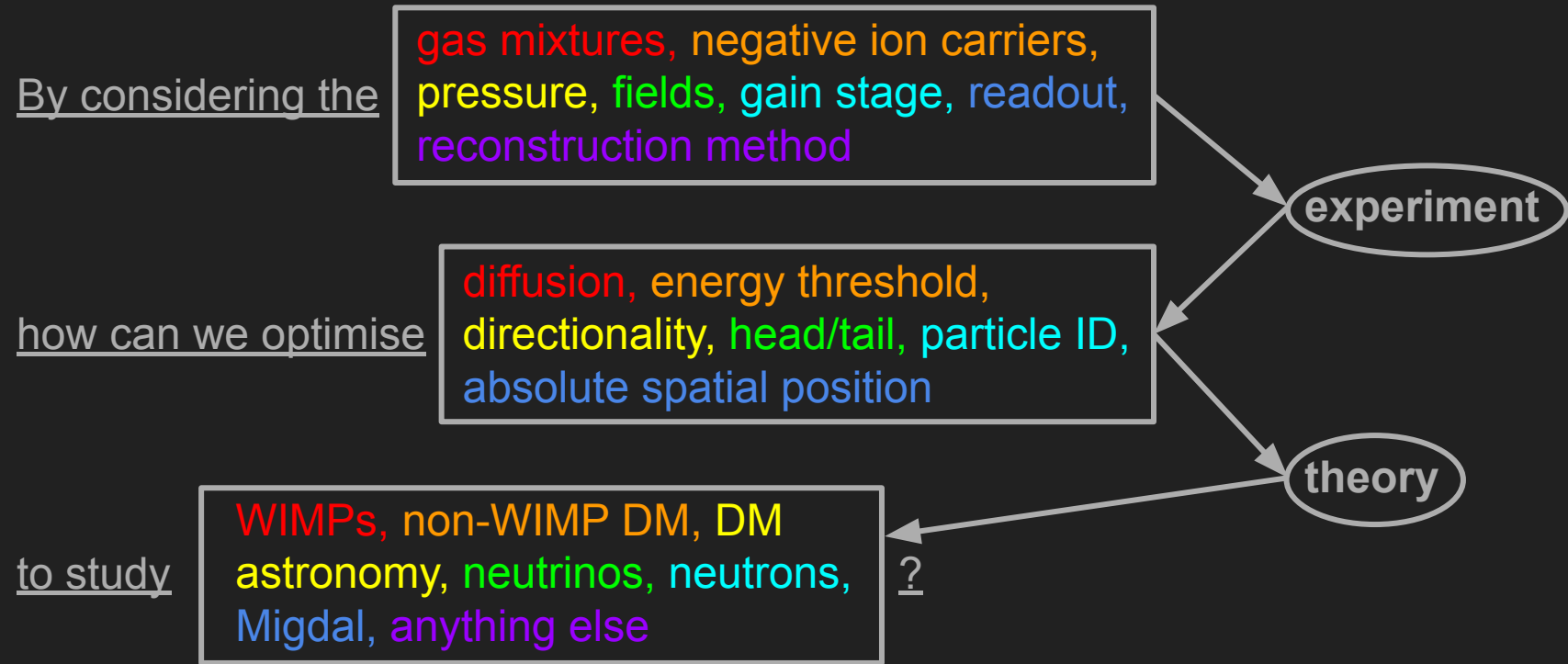
**Neutrinos:** CNO neutrinos,  $^{40}\text{K}$  Geoneutrinos, and more.

**Applications:** Neutron background, defence/homeland security.

**Migdal Effect:** Experimental measurement, light DM search



# CYGNUS - TPC R&D questions



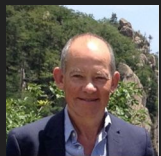
Large design parameter space!

**Other key questions:** backgrounds/material screening, engineering/technical, etc.

# The CYGNUS Proto-Collaboration

- Research programs in Australia, Italy, Japan, Portugal, UK, US
- Australian CYGNUS involvement outlined in CDM proposal, positive feedback from ISAC.
- Snowmass Recoil Imaging White Paper – CDM member contributions
- 2023 Directional detection workshop in Australia

## International Steering Group



N. Spooner, UK  
(spokesperson)



E. Baracchini  
Italy



S. Vahsen  
US



K. Miuchi  
Japan

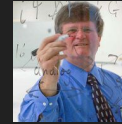
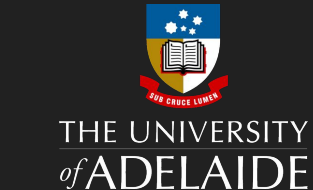
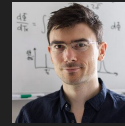
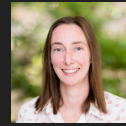
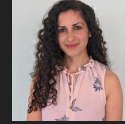
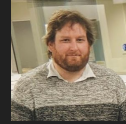
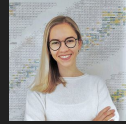


G. Lane  
Australia

## Foreign Institutions



# CYGNUS-Oz Collaboration



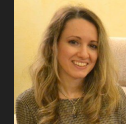
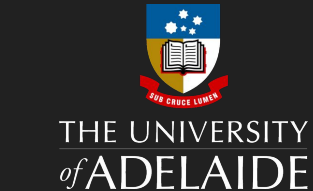
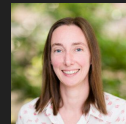
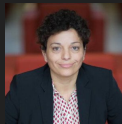
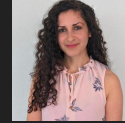
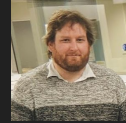
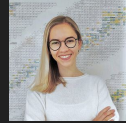
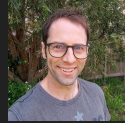
All < 1 FTE on  
CYGNUS-Oz

New members  
welcome!

“Our goal is development of the underlying science, leading towards operation of detectors in Australia as well as participation in international CYGNUS detectors and coordinated analysis. The local Australian detectors are anticipated to include technology development systems at individual Australian Institutions, a 1m<sup>3</sup>-scale demonstrator detector in the Stawell Underground Physics Laboratory and eventual operation of a large-scale directional dark matter detector that will be a part of the international network of directional dark matter detectors that is envisaged to be operated under the CYGNUS banner”, *Collaboration Agreement adopted 8 Sept 2022*



# CYGNUS-Oz Collaboration



All < 1 FTE on  
CYGNUS-Oz

New members  
welcome!

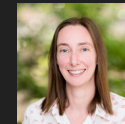
## Institutional Board:



Paul Jackson  
(Adelaide)



Greg Lane  
(ANU, spokesperson)



Nicole Bell  
(UMelb)



Ciaran O'Hare  
(USyd)

Working groups: Experiment, Theory, and Simulation/Reconstruction/Analysis

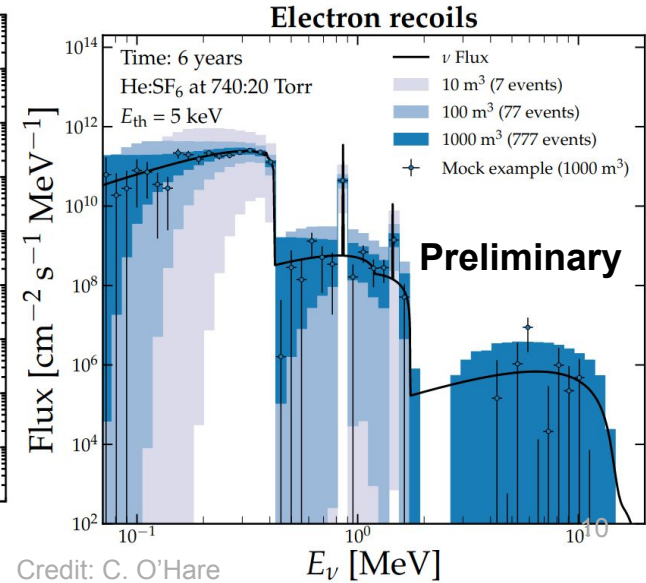
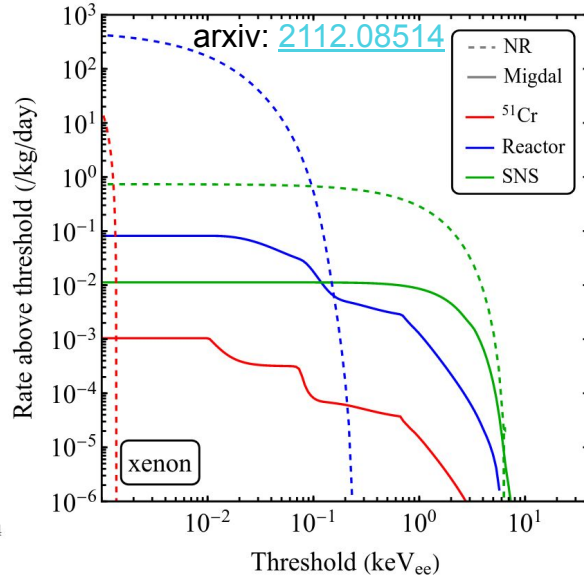
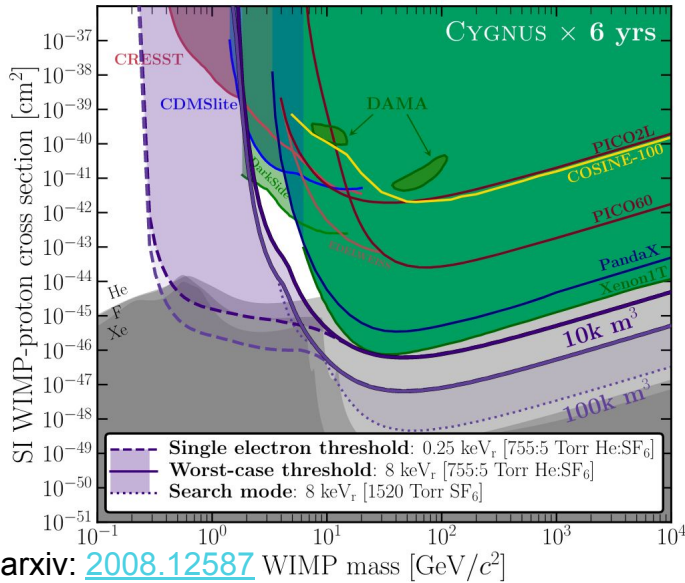
# Theory

CYGNUS WIMP physics case (O'Hare in arxiv: 2008.12587)

Migdal effect in liquid TPC (Newstead in arxiv: 2112.08514)

– investigating gas TPC measurement possibility

CYGNUS solar neutrino physics case (in preparation, multiple CDM contributors)



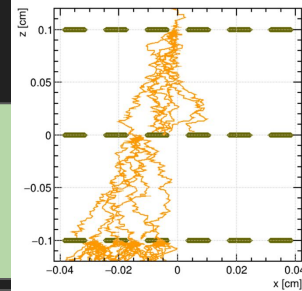
# Reconstruction/analysis

## Detector Parameters

Physical size, gas type, density,  
W-value

longitudinal/transverse diff coeff,  
carrier mobility, drift field

gain distribution,  
PSF, readout pitch



## Primary Event

Deposit track in gas with  
Geant4/HEED/TRIM.

Convert to ion pairs

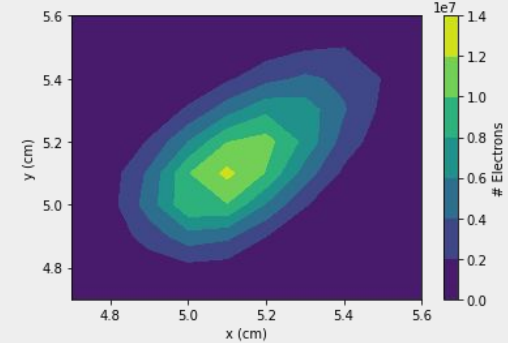
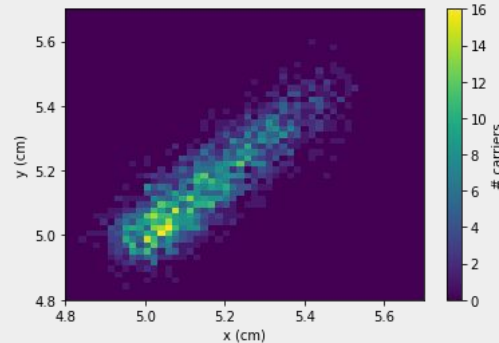
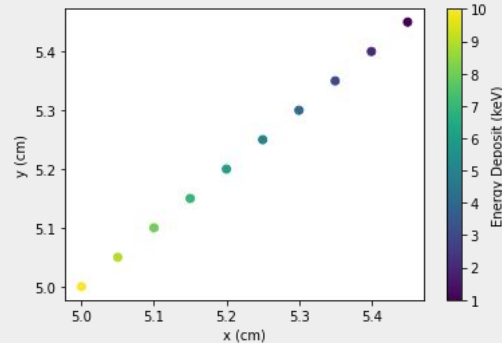
## Drifted Event

Drift carriers to the readout plane

## Readout Event

Apply GARFIELD gain and  
resolution smearing

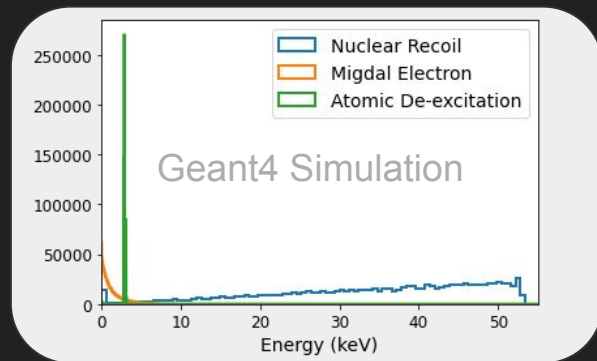
Collect electrons in readout  
channels



# Reconstruction/analysis

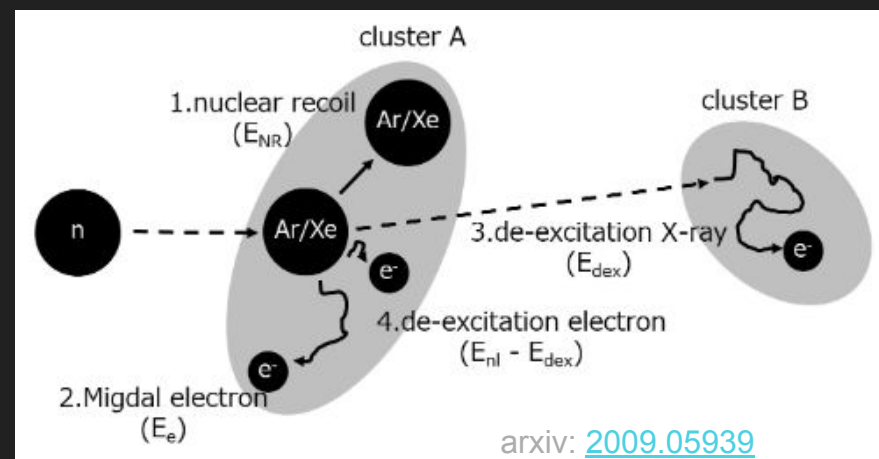
Example: Migdal effect – 1 MeV neutrons

Migdal code (J. Newstead) adapted to Geant4



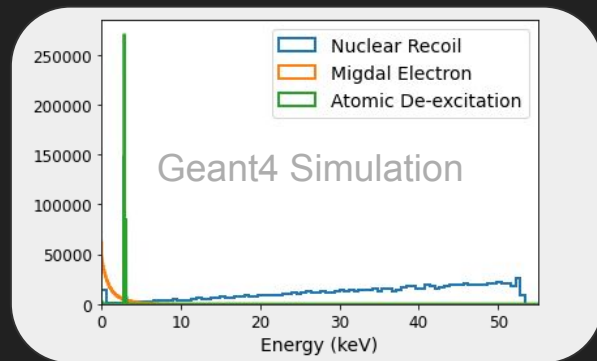
Credit: V. Bashu

**PRELIMINARY**



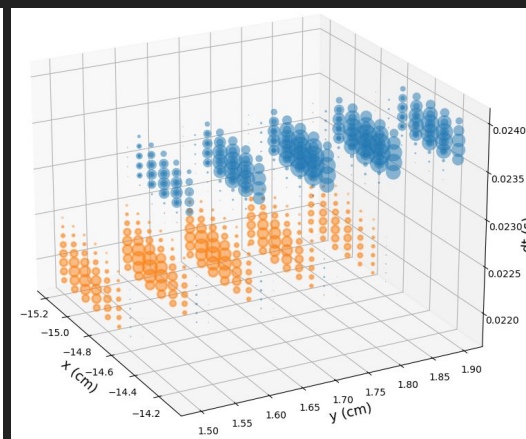
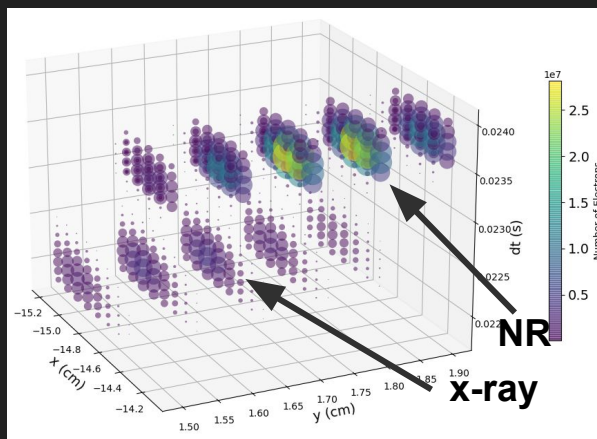
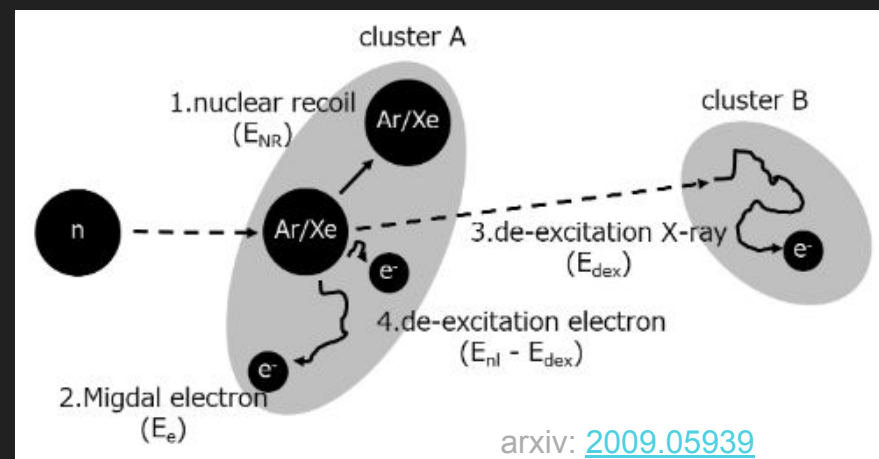
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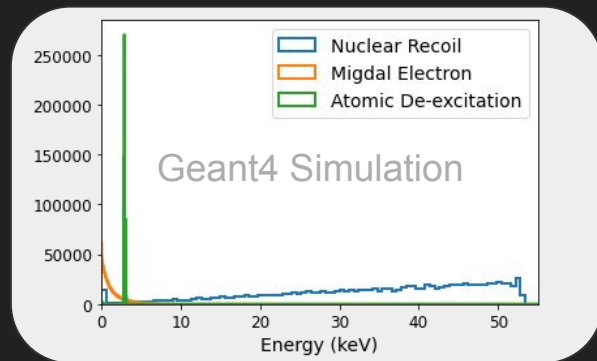
**PRELIMINARY**

Credit: V. Bashu



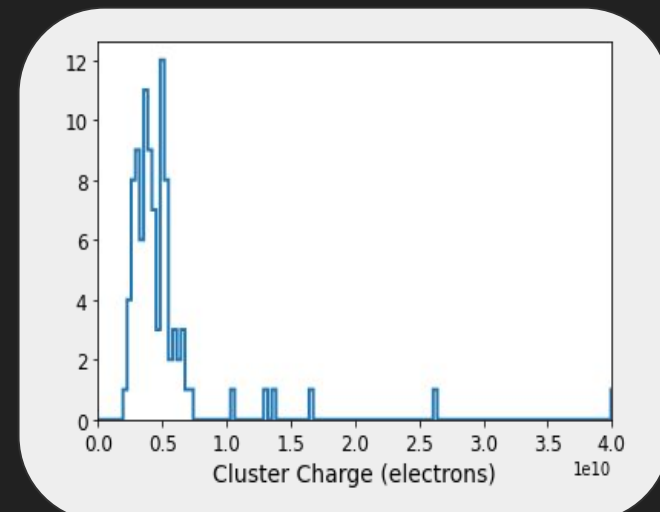
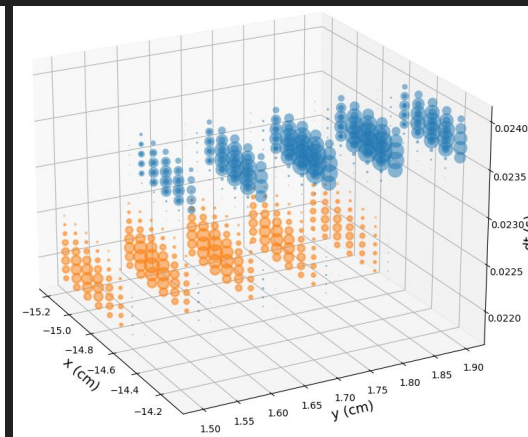
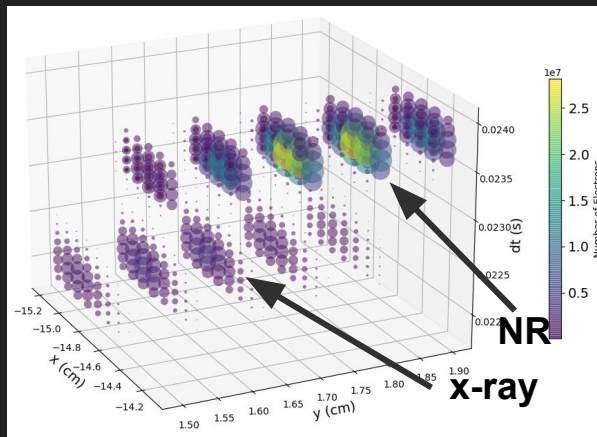
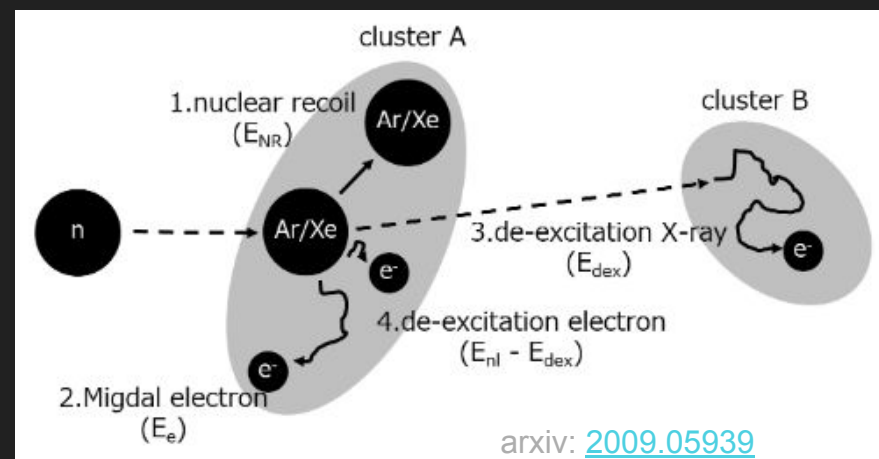
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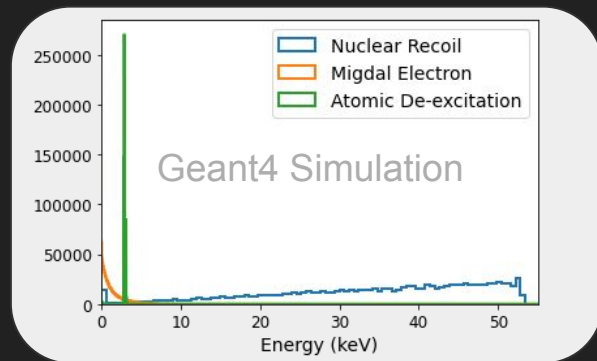
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**PRELIMINARY**



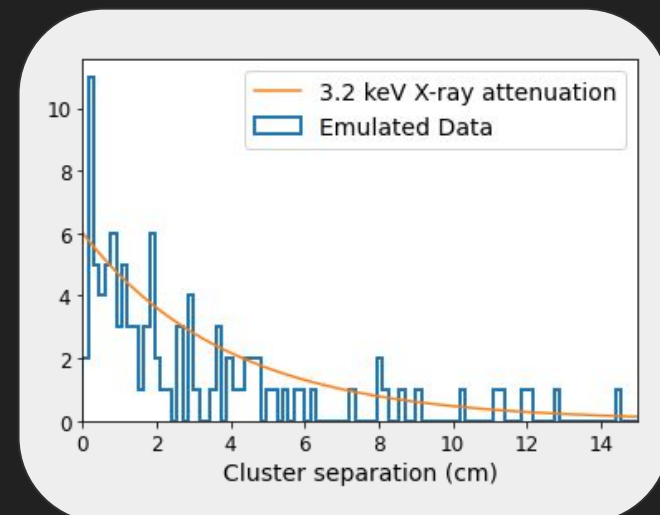
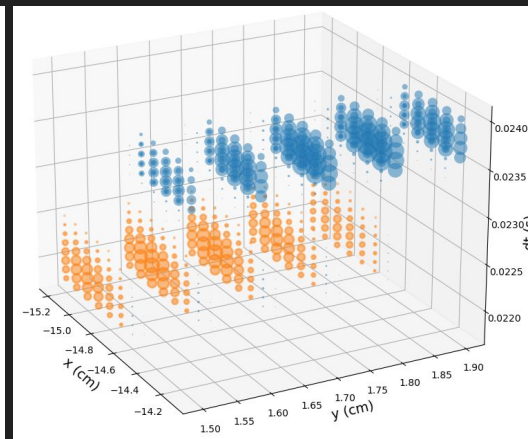
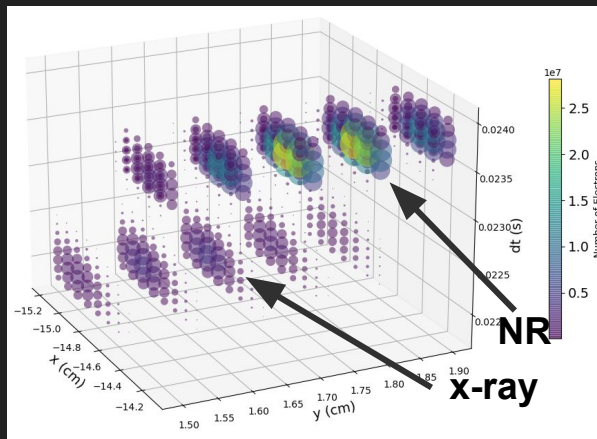
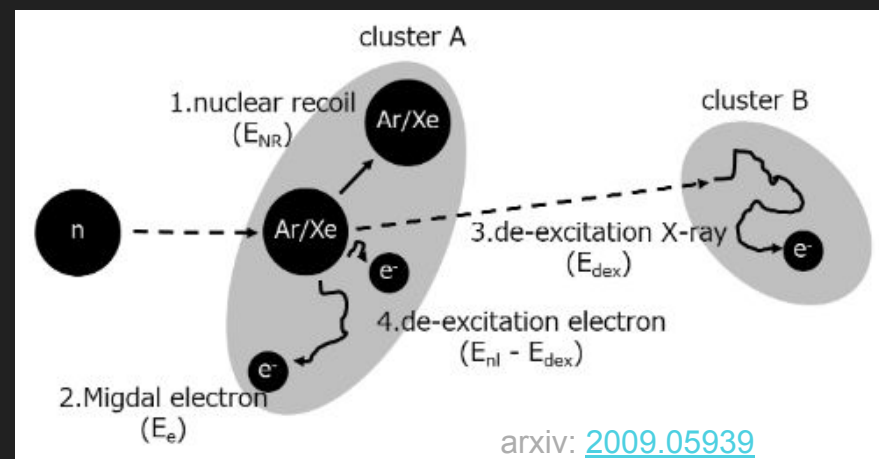
# Reconstruction/analysis

Example: Migdal effect – 1 MeV neutrons  
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PRELIMINARY

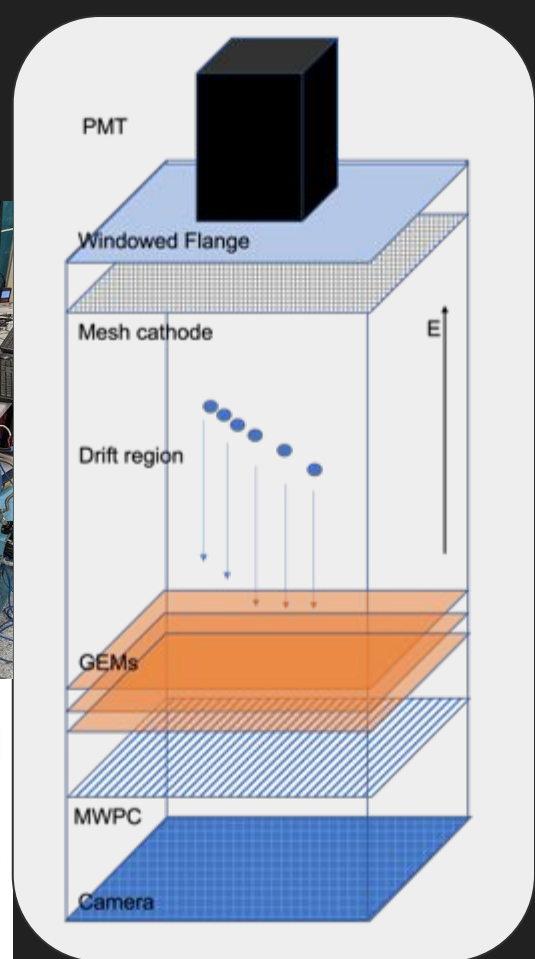
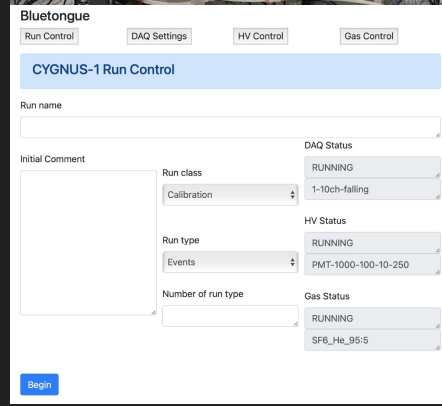
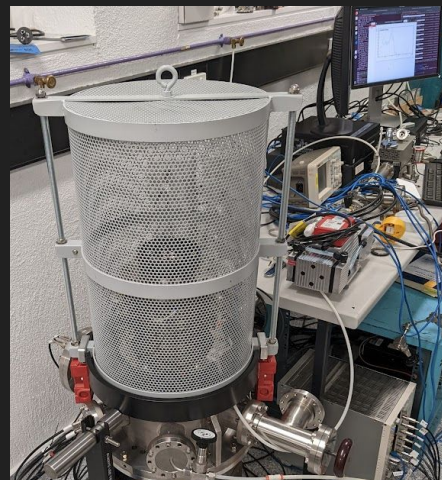
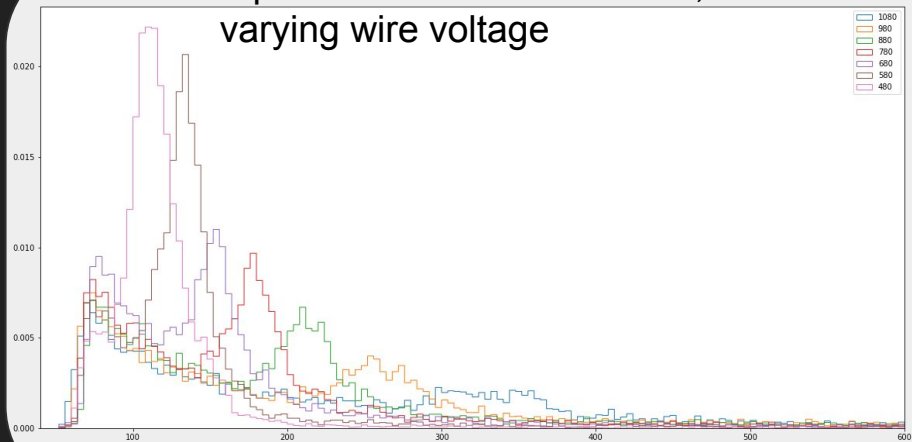


# Experiment: CYGNUS-1

Numerous setbacks: COVID → HV supply → DAQ firmware  
→ GEM failure x5 → RGA failure

Measurements currently using wires only  
for gain – limited to alphas and 4x wires.

Alpha source measurements,  
varying wire voltage



Credit: L. McKie



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Numerous setbacks: COVID → HV supply → DAQ firmware  
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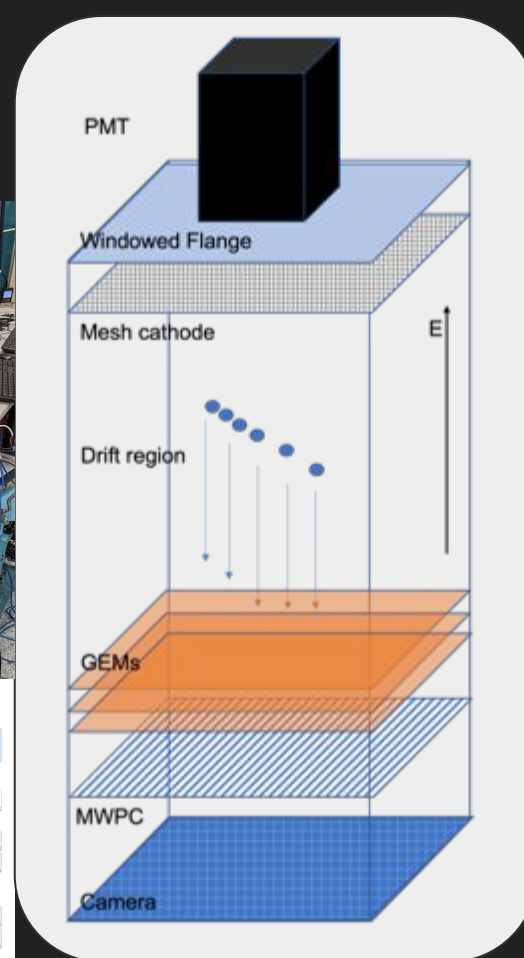
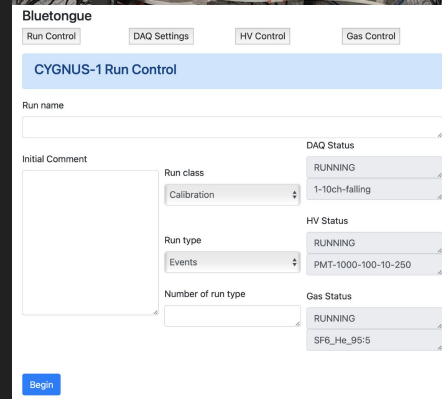
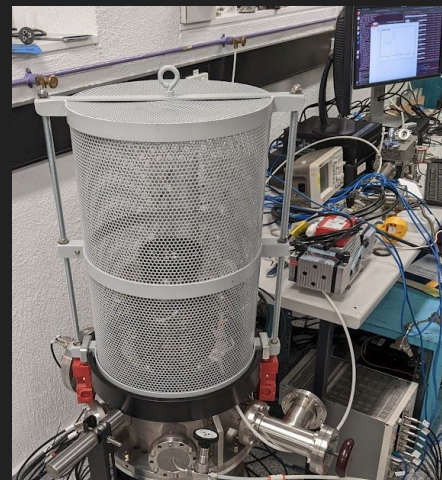
Measurements currently using wires only  
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## Near-term development

New DAQ and GEMs ~Dec 2022

Gas system upgrades (~early 2023  
( $CF_4$  and  $SF_6$  gases)

Intensified camera upgrade (~mid 2023?  
(*high density readout,  
unique capability*)



Credit: L. McKie

# Summary and Future Plans

## Experimental

- CYGNUS-1: gain stage and full channel + optical readout. below-atmospheric pressure control system and  $CF_4/SF_6$  studies.
- Possible experimental TPC work at Adelaide.

## Simulation/reconstruction/analysis

- Opportunities for collaboration with eg. LHC ML experts.

## Theory

- Solar neutrino, ER, and other physics case development.

## Future

- $O(m^3)$  scale prototype in SUPL (post SABRE construction).

### [Confluence link](#)

**CYGNUS**

Space Settings

APPS

+ Add apps

SHORTCUTS

- Bitbucket...
- Jira page
- Experimental...

PAGES

- Fortnightly Meetings
- Details on gem foils
- Cygnus Simulation To...
- Experimental Meetin...
- CYGNUS-1 Experimen...
- Publications
- Literature
- Archived pages

**Communication**

The CYGNUS mailing list is administered by Lindsey. If you'd like to be added please ask him (Slack or [lindsey.bignell@anu.edu.au](mailto:lindsey.bignell@anu.edu.au))

CYGNUS Slack Channels:

- [#cygnus](#) – general discussion, meeting reminders
- [#cygnus-experiment](#) – experiment-specific discussions
- [#cygnus-migdal](#) – discussions relating to the Migdal effect, especially in a CYGNUS-like detector

**Meetings**

The Australian CYGNUS collaborators currently meet fortnightly on zoom; Thursdays at 13:00

Zoom link: [Join our Cloud HD Video Meeting](#)

The international CYGNUS collaboration has two active working groups: the Physics Working Group (focusing on analysis, physics cases, simulation modeling, and similar) and the Gas Working Group (focusing on experimental prototype development and measurements, gas purification, and similar). These working groups meet approximately monthly on Zoom.

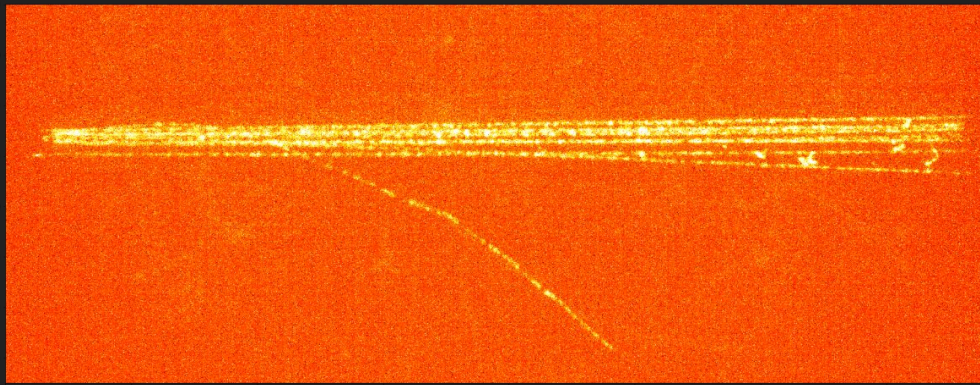
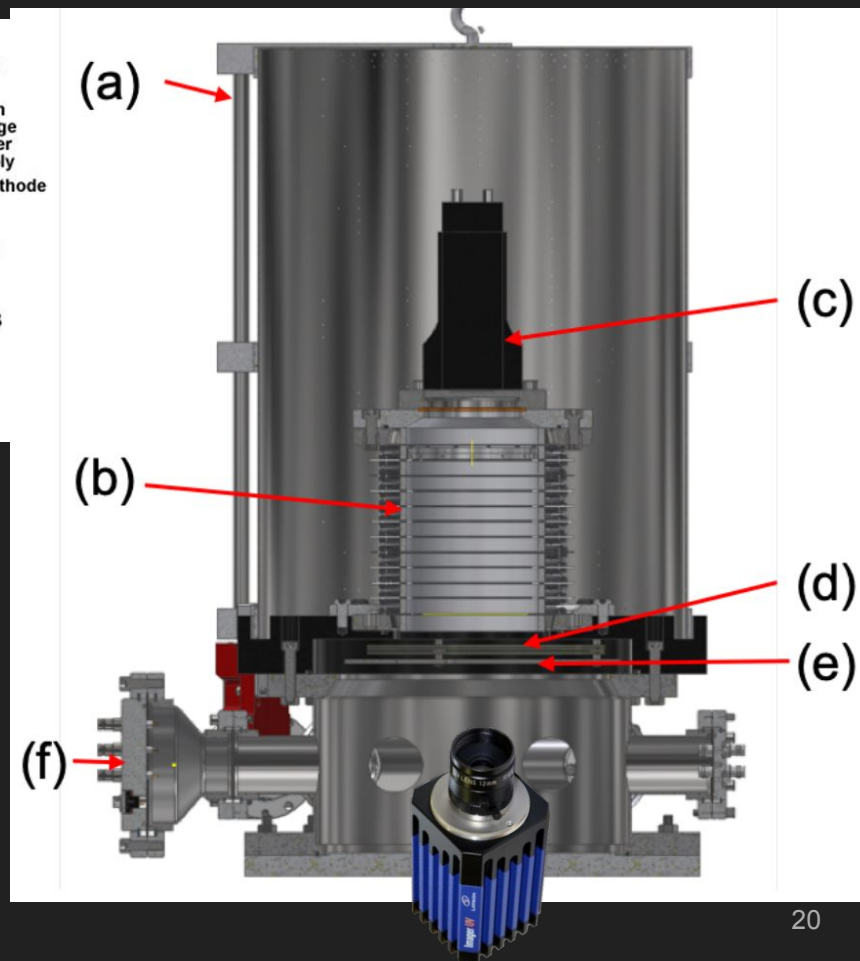
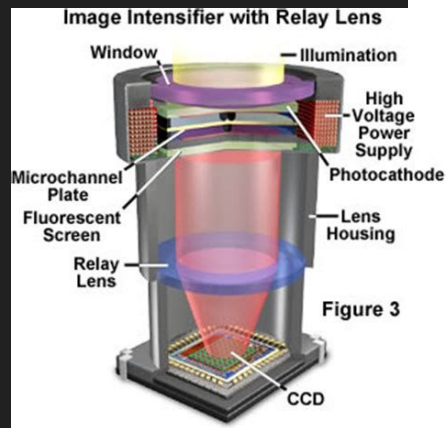


# Australian Experimental Plans

Cygnus-1 upgrade:

Image-intensified Camera

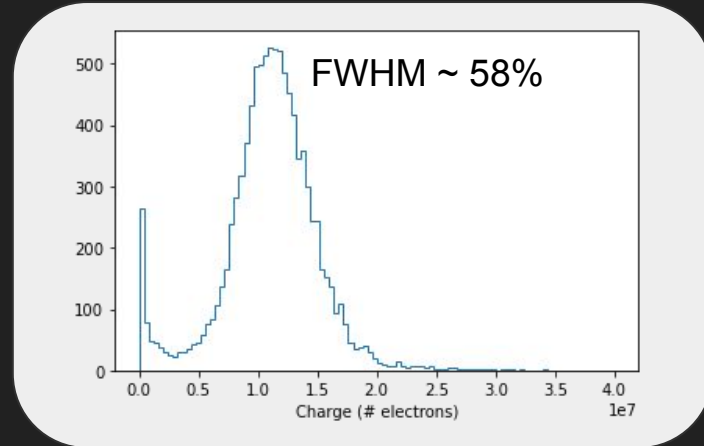
- PMT-like sensitivity, with camera sensor granularity.
  - $< \sim 1$  keV threshold
  - $< 1$  mm granularity
- Triggerable.
  - event-by-event correlated charge/light/image



# Reconstruction/analysis

Example:

3.2 keV gamma rays



Credit: F. Dastgiri